Title
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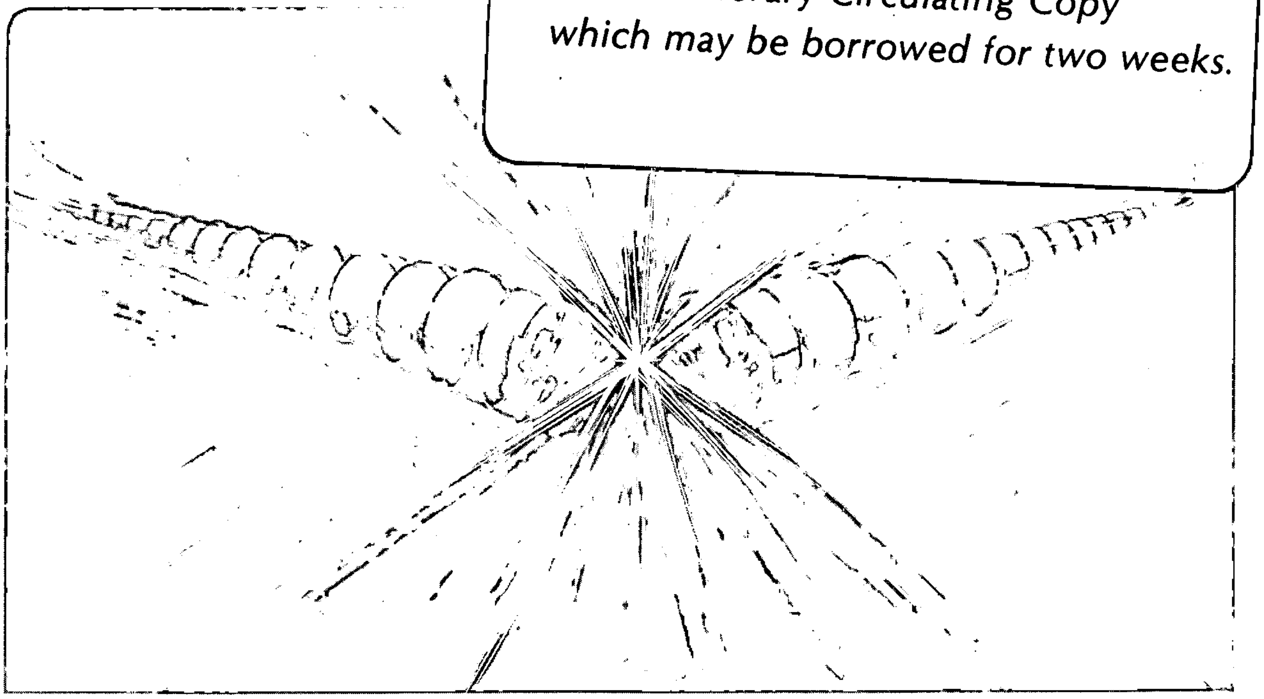

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A d.c. SHEET PLASMA FOR EXTRACTION OF H^- AND D^-*

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Abstract

We are testing operation and H^- yield of a sheet plasma source having a narrow primary electron channel (11cm high, 30cm long, and <1cm wide). The design goal was $J_{H^-} = 30$ mA/cm^2 at V_{arc}=100V, I_{arc}=200A, B<200g, and p_g=5mT. This is similar in geometry and operational parameters to the plasma reported by Uramoto.[1] Conditions outside the sheet are favorable for H^- production; at p_g=10mT (cold fill - 8 sccm), V_{arc}=75V, I_{arc}=125A, and B=200 G, 1cm from the sheet edge, J^+=380 mA/cm^2, T_e=1.4 eV, and $n_e=5\cdot10^{12}$/cm^3, determined from Langmuir probe measurements. The movable negative ion extractor has a circular source aperture of area 1cm^2. J_{H^-} is measured calorimetrically as well as electrically. Agreement of these two signals confirms the effectiveness of the carbon electron dump. Initial extraction at the above conditions produced J_{H^-} =7 mA/cm^2 at 2cm from the sheet edge. This current density is far below the design goals as well as below that reported by Uramoto. We conclude that the sheet geometry is not primarily responsible for the high yield of J_{H^-} in Uramoto's source[1]. Continuing experimentation will be directed towards isolating the effects of the differences between our source and Uramoto's, specifically, his use of LaB_6 cathode, hollow cathode, greater gas flow, wall material / condition, and a different sheet formation mechanism.

Introduction

Large area D^- sources are needed for neutral beam heating systems in future magnetic confinement experiments. A sheet plasma source has been constructed. Testing of it's ability to illuminate a large area with a steady, uniform flux of H^- and D^- has been initiated. Preliminary results are reported that indicate a smaller H or D^- output than anticipated. Experimental investigations are reported which suggest a possible explanation. The apparatus and results are compared with those reported by J. Uramoto, [1] and with filtered magnetic bucket experience.[2]

Experimental Arrangement

The electron channel (typically 0.7cm x 12cm x 30cm) was produced in a predominantly uniform magnetic field (B~50 - 200G). The length of the sheet (30cm), parallel to $\vec{B}$, was determined by the location of the end-plates of the 20cm diameter chamber. The height of the sheet was controlled by the location of the electron emission material (tungsten for the data reported here). Electron access to the anode was sufficient to maintain quiescent operation. Two cup probes (for good ion saturation) of area 0.0507 cm^2 monitored the plasma profile perpendicular to the sheet electron flow: one in the direction of the beam, but opposite (upstream) from the accelerator (Fig.1); the other in the vertical direction (normal to $\vec{B}$ and to the accelerator) at a central location 2cm downstream from the sheet's mid-plane.

The downstream profile (away from the sheet) of extracted H^- or D^- flux was measured with a centrally located, one gap accelerator that could be positioned anywhere between 0 and 8 cm from the sheet's mid-plane. Negatively charged particles were accelerated perpendicularly to the magnetic field of the source. The resulting mass separation permitted simultaneous electrical measurement of the accelerated ions and electrons. The ion flux was also simultaneously measured calorimetrically at the beam dump, which could be independently moved relative to the electron dump. Both aspects were used to ensure that the ion signal was neither inflated by electrons, nor underestimated due to poor ion optics. The graphite electron dump (entire second electrode) minimized the reflection of electrons into the ion beam dump.

Most elements of the plasma chamber were insulated from their neighbors: 2 cathodes, 6 anodes, 2 probes and the beam-forming-electrode. This permitted a fairly detailed picture of the arc current emission and collection pattern. It also allowed the collection of V-I characteristics for various electrodes.

The net pumping speed of the arc chamber's gas exit could be throttled from 5 l/sec to 150 l/sec in order to measure the dependence of H^- and e^- fluxes upon gas flow rate, and hence, upon wall recycling. The operating pressure (measured with a barotron) was restricted to either 2, 5, or 10 mTorr, with most data collected at 5 mTorr. The arc voltage (V_{arc}) could be varied from 40 to 100 V, with most data collected at 75 V. The arc current (I_{arc}) could be varied from 0 to 200 A, but rarely was operated beyond the H or D^- maximum. The available accel voltage is 20 kV, but was usually held near the value where the beam optics were good at the maximum H^- or D^-.

Experimental Observations

The ion density ($n_+ \sim 5 \times 10^{12}$/cm^3) within the sheet was relatively high compared to previous magnetic bucket experience at this pressure (5 mTorr) and arc power (I_{arc}~40A and V_{arc}~75V). As a result, cathode temperature control problems were encountered at high arc power, where ion bombardment dominated the cathode heating. The ion density outside of the hot electron sheet decreased rapidly with distance, falling most rapidly at higher pressure (Fig. 2). The electron temperature (T_e) (Fig. 3) also decreased with distance from the sheet, but was not monotonic at higher currents and lower pressure. Whenever the H^- signal saturated with increasing arc power (Fig.4), T_e always exceeded 2eV within the first few mm beyond the sheet edge. Higher pressure always reduced the electron temperature.

At low arc power, the H^- current increased linearly with arc current. The slope increased slowly with arc voltage, but was independent of neutral density. With sufficient I_{arc}, the H^- current saturated. Higher pressure yielded higher saturation values.

As the accelerator was moved away from the sheet, H^- initially increased and e^- decreased rapidly (Fig. 5). A local H^- maximum was observed coincident with a local e^- minimum at ~2cm from the sheet edge. At larger distances, H^- decreased,

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eventually followed by the electrons. The O^- maximum (40-50% lower than the H^- current) was located further from the sheet (~3 cm) under the same operating conditions. The location of the optimum was only weakly dependent on the magnetic field strength.

No H^- dependence upon gas flow rate (3 to 60 sccm) was observed, provided that the plasma chamber gas exit impedence was adjusted to maintain a constant source pressure with the arc on.

Doubling the sheet width at constant current, pressure, and accel voltage yielded a 40% increase in the maximum accelerated H^- current. Doubling the area of hot tungsten decreased the H^- by 10%

Making nearby surfaces negative (up to 40 V) had only a small effect upon either H^- or e^- currents; regardless of surface size, orientation relative to the magnetic field, or location relative to the accelerator. Positive potentials always reduced the electrons (and sometimes increased the H^- current). The strength of the effect depended upon the magnetic field strength and upon the location, orientation, size, and potential of the electrode.

Discussion

A comparison with Uramoto's sheet plasma is summarized in Table 1. Several differences are noteworthy: 1) Our best H^- current density is 3 to 4 times smaller than his; 2) Our variation with low I_{arc} is linear, while his shows quadratic character; 3) Our H^- current saturates at high power, his maintains its quadratic nature; 4) Our positive ion density shows a gradual decrease outside the sheet, while he observes a plateau; 5) Our H^- optimum is observed at 2 to 3 cm from the sheet, while he reports 8 to 15 cm; 6) Although the sheet dimensions are similar, the sheet formation is very different; 7) Our H^- current decreases with decreasing pressure, while his appears to increase. We conclude that the encouraging results achieved by Uramoto are probably not due to the electron sheet alone. We speculate that the sheet formation mechanism and/or the use of a plasma cathode (both absent in the present experiments) may be the cause of his successes.

The similarity to previous filtered bucket operation is striking. Similar parametric dependences exist, but our saturation occurs at lower arc power and at a lower yield. This suggests that some price has been paid by narrowing (intensifying) the electron channel. This conjecture is supported by the sheet width experiment, where a wider sheet yielded more H^- current for the same arc power. The probe profiles at I_{arc} above H^- saturation all show a narrow region of high density and temperature (>2eV). Hence, we currently suspect that the degradation from previous bucket results has been caused by the higher edge temperature, possibly aggravated by the longer electron collection length and/or the higher primary electron density, and/or the higher sheet density.

The sheet plasma still holds great promise. It provides a simple geometry in which to study H^- or O^- creation and transport. It also is expected to provide a uniform O^- illumination of large multihole accelerators for future fusion heating applications. Efforts will be made to improve the output intensity, including a test of Uramoto's sheet formation method.

Acknowledgments

The authors express grateful appreciation to John Hiskes for many enlightening and stimulating discussions about H^- generation and transport. The authors also appreciate the helpful mechanical and logistical support and suggestions of Steve Wilde and his crew.

References

1. J. Uramoto, Research Report of Institute of Plasma Physics, IPPJ-835 (1987).

2. A. F. Lietzke and C. A. Hauck, "4th Intl. Symp on the Production and Neutralization of Negative Ions and Beams, Brookhaven. AIP Conf. Proc. #158, 259 (1986).

Table 1. Comparison with Uramoto's sheet.

Variable	LBL Sheet Plasma	Uramoto Sheet Plasma
I_{arc}	0-130 A	0-200 A
Arc Dependence	Linear with a saturation	quadratic character
V_{arc} (max)	75(110) V	~80-120
B field	50-200 G	60-100 G
$J(H^-)$ Absolute max observed	7 mA/cm^2	~ 24 mA/cm^2
Optimum position for extraction	2-3 cm	~ 15 cm
Hot e^- region Dimensions	0.7 x 12 x 30 cm	~ 1 x 20 x 50 cm
Electron source	Hot tungsten	LaB_6 in a dual plasmatron arrangement
Sheet formation	Extended cathode	Transformation of round plasma beam into a rectangular sheet
Accelerator	1 Gap	2 Gap
Hole size	Round, 1 cm^2	Round, 0.28 cm^2
Variations with pressure increase at constant arc current	Increasing or invariant	Decreasing

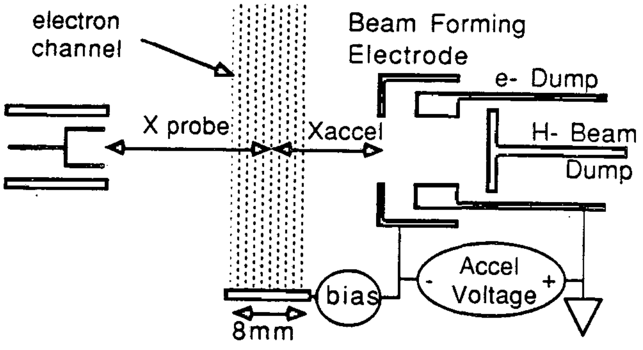

Fig. 1 Diagnostic Geometry. Probe is roughly 4x scale. Accelerator is roughly 0.6x scale.

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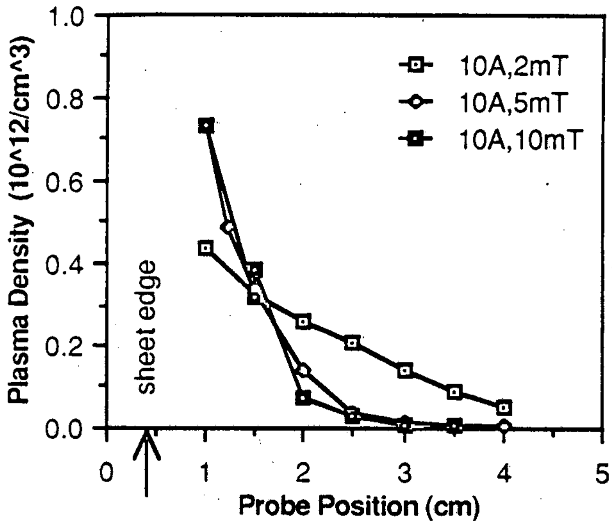

Fig. 2a Plasma Density at Iarc below saturation

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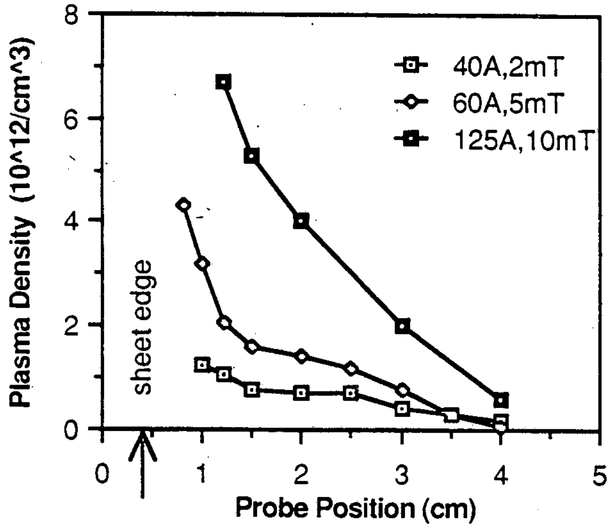

Fig. 2b Plasma Density at Iarc above saturation

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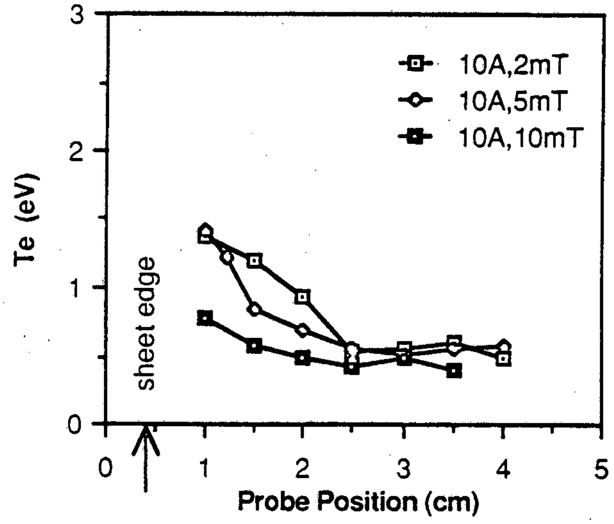

Fig. 3a Te at Iarc below saturation

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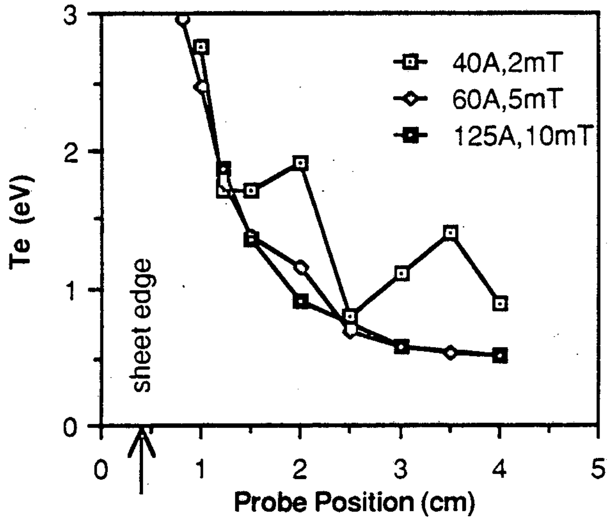

Fig. 3b Te at Iarc above saturation

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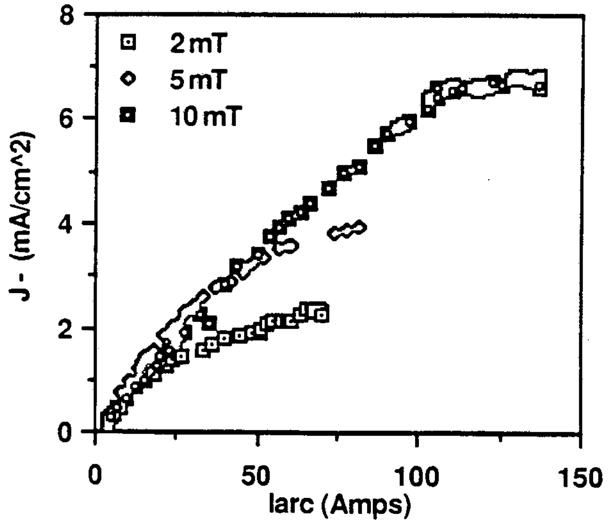

Fig. 4 H- versus Iarc at 3 pressures

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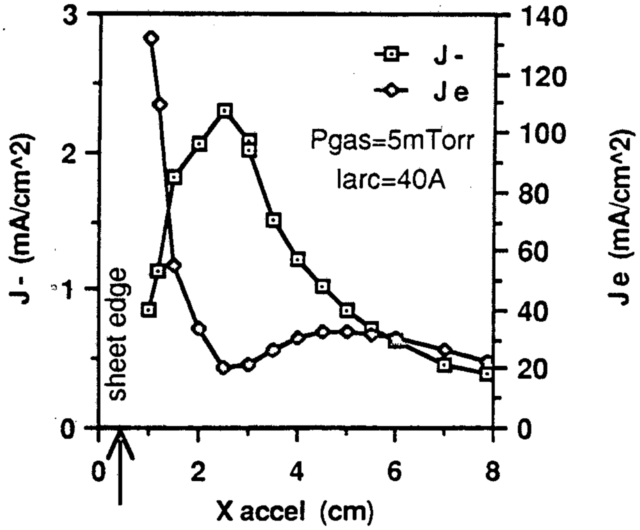

Fig. 5 Typical H- & e- versus accel position

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